Structure and Reactions with Exotic Nuclei within the **INFN-PI32** network.

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Abstract

The INFN (Italian National Institute for Nuclear Physics) has approved a national theoretical network on "Structure and Reactions with Exotic Nuclei". The project involves the INFN branches of Laboratorio Nazionale del Sud, Padova and Pisa. The aim of the project is to start coordinating and to homogenize the research already performed in Italy in this field and to strengthen and improve the Italian contribution on the international scenario. Furthermore it aims at creating a solid theoretical structure to support future experimental facilities at the INFN national laboratories such as SPES at LNL and EXCYT at LNS. A review of present and future activities is presented.

1 Introduction

Since a few years an increasing number of Italian theoreticians has concentrated his research on the study of exotic nuclei. Such activities have so far

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been carried out within pre-existing national projects related to a wide spectrum of themes of nuclear dynamics, structure and reactions using many body techniques, shell model, collective modes and semiclassical or fully quantum mechanical approaches to peripheral and central reactions such as transfer and breakup, fusion, elastic scattering via microscopic optical potentials, multifragmentation.

The goal of our project is to start coordinating and homogenizing such efforts to improve our mutual understanding, and to strengthen the Italian contribution on the international scenario. Furthermore our efforts will help creating a solid theoretical structure to support future experimental activities at the INFN national laboratories.

In fact, in the last two decades, the use of radioactive beams of rare isotopes in several laboratories around the world (REX-ISOLDE at CERN, GANIL in France, GSI in Germany, CRC, Louvain la Neuve in Belgium, RIKEN in Japan, DUBNA in Russia, Argonne, MSU, Oak Ridge, Notre Dame in USA , etc.) has provided new research directions and an increasing number of researchers all over the world is converging on such subject. The INFN in Italy is also heavily involved in this field. The facility EXCYT and the large acceptance spectrometer called MAGNEX are being completed at Laboratorio Nazionale del Sud. On the other hand the first step of the SPES project at the Laboratorio Nazionale di Legnaro has been approved in the form of a proton driver. Furthermore the INFN is promoting the new European Radioactive Beam Facility (EURISOL). Members of our collaboration are actively participating in NuPECC working groups, in particular in the preparation of "The Physics Case" for EURISOL, whose report is available at http://www.ganil.fr/eurisol/Final_Report/A-Physics-Case-20-Dec-02.pdf, and in general of the NuPECC Long Range Plan.

The relatively new subject of exotic nuclei is of fundamental importance because while all existing theories for the nuclear interaction and the many body nuclear structure have been based on the study of stable nuclei, very little is known about the way in which standard nuclear models work for the description of unstable nuclei with anomalous N/Z ratio. Important questions to answer are for example: the isospin dependence of the effective nuclear interaction, the modification of the traditional shell sequence with possible vanishing of the shell gaps, the persistence of collective features, the properties of nuclear matter at very low density, the form of the EOS for asymmetric nuclear matter. Similarly in the field of nuclear reactions still open questions are the identifications of the most important reaction

channels and the clarification of the associated reaction mechanisms. Many of these features are also related to nuclear reactions of astrophysical interest such as those governing the primordial nucleosyntesis.

The proposed research activity will deal with the following aspects: reaction mechanisms and structure information extraction for nuclei close to the driplines, single particle and collective degrees of freedom, dynamical symmetries at the phase transitions, dynamics of heavy nuclei with anomalus N/Z ratios and isospin degrees of freedom, equation of state. The partecipants have complementary competences in the fields of structure and reaction theory. They have common national (LNS,LNL) and international collaborations (ie : IPN, Orsay; GANIL, Caen, France, MSU, USA, etc.). Their present abilities and activities in the above research fields are described in the following.

2 Reaction Mechanisms by the Pisa Group

In Pisa there is a longstanding tradition for studying peripheral reactions such as transfer and breakup, therefore it has been easy and natural to tourn our attention to the study of halo nuclei [1-8].

In recent years we have concentrated on a consistent treatment of nuclear and Coulomb breakup and recoil effects treated to all orders and including interference effects. We have developed a formalism which allows the calculations of energy, momentum and angular distributions for the core and halo particle and absolute cross sections. The possibility of calculating so many observables is almost unique to our model. The dependence on the final state interaction used has been clarified and also the accuracy of the eikonal model compared to fully quantum mechanical theories has been established.

An extension of the method to proton breakup has been recently presented and we plan to apply it to the study of reaction of astrophysical interest such as those involving ^{8}B. Finally a microscopic model for the calculation of the optical potential in the breakup channel has been developed. The method originally used to calculate elastic scattering of halo projectiles on ligth targets is now being extended to heavy targets by the inclusion of recoil effects. Also we are extending our techniques to the calculations of angular correlations.

In the last period we have started to study nuclei unbound against neutron emission, such as ^{10}Li and ^{13}Be. They are the constituents of two neutron

halo nuclei (i.e. ^{11}Li and ^{14}Be). The study of their low lying resonance states is of fundamental importance for the understanding of two neutron halo nuclei. The final goal is to clarify the structure of the core-neutron interaction. This is by no means a trivial task as such cores are themselves unstable nuclei (^{9}Li, ^{12}Be) and therefore cannot be used as target in experimental studies. We are at present discussing the differences between the technique of projectile fragmentation and of transfer to the continuum in order to understand whether they would convey the same structure information. This line of research is leading us naturally to study the structure of few-body systems which we plan to undertake in a near future.

3 Reaction Mechanisms and Structure of Rare Isotopes by the Padova Group

The Padova group has similar and complementary lines of research as the Pisa group as far as reaction mechanisms are concerned. However it has a special interest for a somehow lower energy domain where fusion and the coupling to breakup channels are particularly important [9-24]. Besides it is active in studying structure problems such as:

- Study of the pairing correlations in low-density nuclear systems, as in the external part of halo nuclei.

- Microscopic estimate of inelastic excitation to the low-lying continuum dipole strength via microscopic continuum RPA calculations.

- Study of isospin symmetry in low- and high-spin states in medium-mass N=Z nuclei up to ^{100}Sn. Study of the interplay of T=0 and T=1 pairing.

- Study of nuclear structure with algebraic models. This line of research is associated with the use of algebraic models, as the Interacting Boson Model or its variations, to describe different aspects of nuclear spectra. Our traditional approach is based on the use of the concept of boson intrinsic state. In this framework we will study the new symmetries E(5) and X(5) associated with phase transitions and individuate mass region far from stability where such critical points may occur.

- Study of the role of continuum-countinuum coupling in the break-up of weakly-bound nuclei.

4 Isospin Dynamics in Reactions with Exotic Beams at LNS

Two teams are active at the LNS. One is working in the energy range from the Coulomb barrier (Tandem) to the Fermi energies (Superconducting Cyclotron). Our main motivation is to extract physics information on the isovector channel of the nuclear interaction in the medium from dissipative collisions in this energy range using the already available stable exotic ions and in perspective the new radioactive facilties. We have developed very reliable microscopic transport models, in a extended mean field frame, for the simulations of the reaction dynamics in order to check the connection between the tested effective interactions and the experiments, in particular for the isospin degree of freedom [25-39]. This work is of interest for the understanding of the physics behind the reaction mechanisms and for the selection of observables most sensitive to different features of the nuclear interaction. Moreoever we have a more general theoretical activity on the isospin dynamics in nuclear liquid-gas phase transitions. New instabilities have been evidenced with a different "concentration" between the gas and cluster phases, leading to the Isospin Distillation effects recently observed in experiments. A quantitative analysis can give direct information on the density dependence of the symmetry term for dilute asymmetric matter, i.e. around and below saturation. We remind the poor knowledge of the isovector part of the nuclear effective interaction at low densities, which is actually of large interest even for structure calculations of drip line nuclei.

The main results obtained in the last year are related to:

1) Isospin dynamics in low energy dissipative collisions.

2) Isospin in Nuclear fragmentation.

5 Finite Nuclear Systems in Brueckner Theory at LNS

The second team at LNS is interested in relating nuclear properties to elementary interactions between nucleons and to build up an energy density functional starting from a more fundamental level than the present phenomenological energy functionals of non-relativistic mean field or RMF [40-46]. This can be achieved because of the familiarity of the group with the

Brueckner theory in infinite nuclear matter including 2-body and 3-body forces. It has been shown that the inclusion of 3-body forces in the Brueckner theory is necessary for obtaining the correct saturation point of nuclear matter and going away from the so-called Coester line. From the results of infinite matter one will construct an energy density functional which can give the same results in nuclear matter and also can be used in finite nuclei. This is quite similar to the energy functional method of atomic physics based on ab initio calculations of the homogeneous electron gas and the local density approximation (LDA). This nuclear energy functional should be trustable away from the stability region since no adjustment will be made to reproduce the properties of stable nuclei, contrarily to phenomenological energy functionals whose extrapolations can be questionable.

The proposed method is a simpler alternative than direct Brueckner calculations of finite systems. It also allows for studies of excitations of nuclei, within RPA-type of calculations built on top of the mean field ground state. This is again in the same spirit as the time-dependent LDA (TDLDA) method which has proved very successful in atomic cluster physics. The main objectives of the project are:

- BHF calculations of asymmetric and polarized matter.
- Construction of the energy functional.
- Ground states of finite nuclei.
- Excitations of finite nuclei.
- Neutron star crust

6 Conclusions

We have presented the main research lines of the new INFN-PI32 theory network on exotic nuclei. They span from low energy reaction theory for elastic scattering and fusion, to intermediate energies studies for breakup and multi-fragmentation for the understanding of the isospin degree of freedom. Structure studies on the pairing problem, on algebraic models and on the Brueckner theory are also actively pursued.

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